THE MIXED INITIATIVE EXPERIMENTAL (MIX) TESTBED FOR HUMAN ROBOT INTERACTIONS WITH VARIED LEVELS OF AUTOMATION

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ABSTRACT

In 2007, the U.S. Department of Defense (DoD) released a report detailing the future of robotic military equipment and how to proceed in development and procurement of unmanned systems (Office of Secretary of Defense, 2007). This document recognizes the role of unmanned systems in the areas of reconnaissance, surveillance, and target identification. This role for unmanned systems implies a need for improved warfighter support and training. The Mixed Initiative Experimental (MIX) Testbed is a distributed simulation environment which provides a means for this type of training. This paper describes the design and capabilities of the MIX Testbed and exemplar scenarios for research and training with unmanned systems of varying capabilities.

1. INTRODUCTION

To address the growing use of unmanned systems in military operations, the U.S. Department of Defense (DoD) released a report detailing the future of robotic military equipment and how to proceed in their development and procurement. This document, The Unmanned Systems Roadmap, incorporates master plans for unmanned air, ground, undersea, and surface systems over the next twenty five years into a comprehensive roadmap for future prioritization of development and DoD needs (Office of Secretary of Defense, 2007). This report recognizes the increasing role of unmanned systems in the areas of reconnaissance, surveillance, and target identification. This role implies the need for improved warfighter support and training with this new technology and its increasing capabilities. Moreover, the roadmap identifies interoperability between unmanned systems as a requirement for reducing procurement and training costs.

With the capabilities of unmanned systems growing (e.g. autonomous navigation), researchers need to investigate how warfighter performance is affected. For example, does an increase in the level of automation result in a decrease in situational awareness? There has been much research conducted in the area of human team performance (Dixon and Wickens, 2003; Driskell, Radtke, and Salas, Sims, and Burke, 2005), but there still remain questions for optimizing operational systems for "mixed-initiative" teams. Mixed-initiative interactions refer to a flexible interaction strategy in which each agent (human or computer) contributes what is best suited at the most appropriate time (Hearst, Allen, Guinn, and Horvitz, 1999).

The MIX Testbed is a distributed simulation environment for investigation into how unmanned systems are used and how automation affects performance. The MIX Testbed includes an Operator Control Unit (OCU), Unmanned Vehicle Simulator (UVSIM), and interoperability with existing DoD simulators using HLA and the Joint Architecture for Unmanned Systems (JAUS). The default simulated unmanned system included with the testbed is an Unmanned Ground System (UGS). This platform includes a camera payload, and supports multiple levels of automation. The OCU provides a standard interface for users to control any type of unmanned system supporting JAUS like the simulated UGS. Users can send mission plans or teleoperate the platform with a joystick while being provided a video feed from the camera payload; tasks typical in reconnaissance and surveillance.

To directly support experimentation, the MIX Testbed includes extensive data and event logging capabilities in addition to neurophysiological devices for measuring a user's state. Devices that measure heart rate, Electrocardiogram (EKG), Electroencephalogram (EEG),

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Galvanic Skin Response (GSR), and gaze location can be used to measure workload and user performance in conjunction with data-driven methods within the test environment (Nicholson, Stanney, Fiore, Davis, Fidopiastis, Finkelstein, Arnold, 2006).

The work presented here discusses on-going research at the University of Central Florida's Institute for Simulation and Training targeted at investigating mixed-initiative teams and unmanned systems operator performance, sponsored by the U.S. Army Research Lab (ARL) and U.S. Army Research Development and Engineering Command (RDECOM). It presents the design, implementation, and capabilities of the MIX Testbed and how it is used for research in Human-Robot Interactions (HRI) for reconnaissance, surveillance, and target identification.

Section 2 of this paper provides the design and goals of the MIX testbed. Section 3 describes the implementation of the main components which include: Operator Control Unit (OCU) and Unmanned Vehicle Simulator (UVSIM). Section 4 describes how the capabilities of the MIX Testbed are used in example scenarios for HRI research.

2. DESIGN

In order to meet the goals of training and experimentation with mixed-initiative teams the MIX Testbed is designed with two primary requirements: interoperability with existing distributed simulations and measurement of user performance and state. By maximizing interoperability with existing DoD simulations, the MIX Testbed can add functionality that is missing without having to redevelop existing capabilities. Experimentation is supported by including data logging capabilities into MIX components that record simulation events, user interactions, and neurophysiological sensor data.

The MIX Testbed includes three primary components: UVSIM, OCU, and Joint Semi-Automated Forces (JSAF). UVSIM simulates different types of unmanned systems such as ground or air vehicles. The OCU allows users to interact with unmanned systems generated by UVSIM for reconnaissance, surveillance, and target identification missions. Finally, JSAF generates simulated entities that simulated unmanned systems and other compatible simulations can interact with.

Interoperability within the MIX Testbed is accomplished using two standards: HLA and JAUS. HLA is a DoD standard used in many distributed simulations allowing MIX components to work with existing simulations like those included with the Deployable Virtual Training Environment (DVTE), (Dahmann, 1997; Bailey and Armstrong, 2002). JAUS is a component-based message passing architecture that describes services that unmanned systems support, and is recommended by the Unmanned Systems Roadmap. Moreover, JAUS is independent of any specific hardware or technology, allowing operators to learn one set of commands that can be used on any type of unmanned system (JAUS Working Group, 2008). An additional component is included in the system design to bridge HLA and JAUS traffic, allowing HLA Federates to interact with components using JAUS as shown in Figure 1.

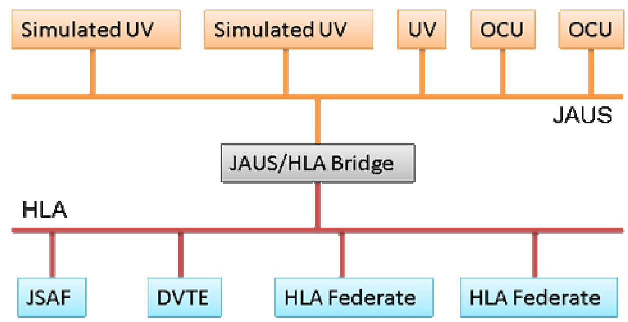

Figure 1 - Distributed simulation design

The OCU application is the primary interface used by participants for human robot interactions. It incorporates interfaces to the neurophysiological sensors (e.g. heart rate monitor, eye tracker) used to measure a users' state. Sensor data, scenario events, and user interactions are time stamped and logged for each experiment by the OCU.

3. IMPLEMENTATION

3.1 Deployable Virtual Training Environment (DVTE)

DVTE is a training and testing environment that provides distributed simulation capabilities. Developed for the U.S. Marine Corps, it is a deployable suite of simulators that run on identical, commercially available laptop computers. One component of DVTE called the General Simulator (GENSIM) is an application that provides a three-dimensional, networked, HLA environment encapsulating different positions within Fire Support (FiST) and Close Air Support (CAS) teams. Team positions that can be trained or tested include mortar and artillery Forward Observers (FO), Forward Air Controllers (FAC), FiST Leaders, and drivers/pilots and gunners for the following vehicles: AH-1, AV-8B, UH-1, CH-53, LAV, AAV, and M1A1. Included with DVTE for scenario development is JSAF. JSAF is the main component for generation of interactive scenarios that support multiple simulated entities. DVTE provides an existing distributed simulation environment and is used within different configurations of the MIX Testbed. The UVSIM and OCU components augment DVTE by

providing unmanned systems capabilities for training mixed-initiative teams.

3.2 Unmanned Vehicle Simulator (UVSIM)

The UVSIM application is used to generate ground or air unmanned systems that support JAUS as a command and control interface. By providing a standard interface, users only need to learn one command set, reducing training time. JAUS also describes a set of services that unmanned systems can support. For example, the Global Pose Sensor service provides position and attitude information about a vehicle. Messages within the standard allow interfaces to query the system for supported services letting operators discover the capabilities of unmanned systems dynamically.

UVSIM is implemented in C++ using Open Scene Graph and the JAUS++ library created by the ACTIVE Laboratory. JAUS++ is a C++ implementation of JAUS that provides interfaces for common services in addition to a complete message set. Using Open Scene Graph, a 3D environment is generated for interactions within the environment and video streaming. UVSIM can be run in a distributed manner with single or multiple unmanned systems on each networked machine depending on hardware capabilities.

UVSIM can operate with existing HLA, simulations like DVTE, using a JAUS/HLA bridge, and also supports standalone capabilities. Through an Extensible Markup Language (XML) configuration file, users can add static models within the simulated environment. Any 3D model supported by Open Scene Graph can be loaded and placed at a pre-determined location for creation of controlled conditions between missions.

Each simulated vehicle supports a common set of services for providing pose and video information, but do not support the same level of automation. The UGS simulation in the current implementation of MIX supports two types of automation: waypoint navigation and aided target recognition (AiTR). Waypoint navigation allows operators to send a pre-planned mission route to the vehicle. The UGS will follow the given route, pausing at designated checkpoints in the mission plan. The AiTR pans the vehicle's camera (up to 360 degrees), scanning for targets within the environment. The resulting scan identifies a list of all targets (friendly and unfriendly) within the scene as shown in Figure 2.

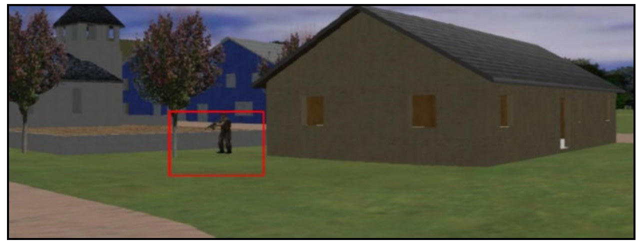

Figure 2 - Aided target recognition scan

With the two automations provided, four control conditions can be produced with the simulated unmanned system: teleoperation with no AiTR, teleoperation with AiTR, autonomous navigation with no AiTR, and autonomous navigation with AiTR.

3.3 Operator Control Unit (OCU)

The Operator Control Unit is the primary interface used for interactions with unmanned systems used for reconnaissance, surveillance, and target identification, and replicates the look of the Tactical Control Unit developed by General Dynamics and ARL (General Dynamics, 2008). It is also developed in C++ with Open Scene Graph and the JAUS++ library for communication. It contains a "gods-eye" view of the map showing the current location of all unmanned systems available for control. An asset summary list allows users to select specific unmanned systems. A navigation bar allows for zooming in/out and movement across the map. There are four main screens that can be selected from the toolbar at the bottom of the screen: Teleoperation, Reconnaissance, Surveillance, and Target Acquisition (RSTA), Video, and Map.

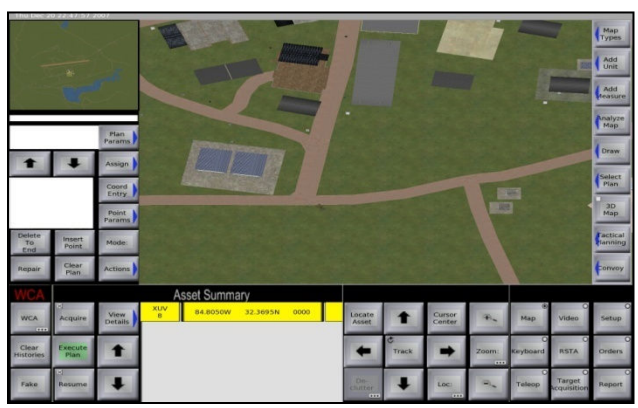

Figure 3 - Operator control unit

When an asset is selected and the Teleoperation screen is selected, users can remote control the vehicle using an attached joystick. Video from the vehicle is displayed on screen in addition to the "gods-eye" view of the map. The Video screen looks identical to the teleoperation screen; however users are not in direct control of the vehicle.

From this screen, users can monitor the environment while a vehicle is navigating autonomously. The Map screen, Figure 3, is used to plot mission plans for unmanned assets capable of autonomous navigation. Finally, the RSTA screen, Figure 4, displays all AiTR scans received from an unmanned asset. From this screen operators can send an AiTR command, place markers on the map representing identified targets, and send reports containing threats detected.

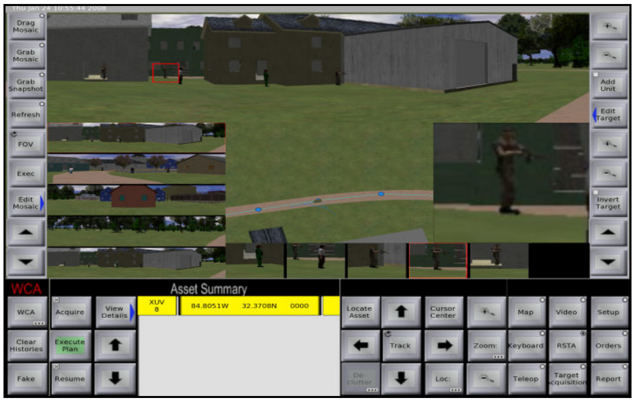

Figure 4 - RSTA screen

As shown in Figure 4, the RSTA screen contains a list of all AiTR scans received on the left side. Users select an AiTR scan from this list which results in the larger image being shown at the top, along with all identified targets, called chips, shown on the bottom. The center of the screen displays the "gods-eye" view of the map. When a chip is selected, a red box is shown in the larger scan image to show where the target is in the scene. Using a menu on the right, operators can identify chips as friendly, neutral, or enemy targets, and place an icon on the map.

Mission plans developed using the OCU designate a series of waypoints and checkpoints that a vehicle must navigate. Checkpoints indicate locations where the vehicle should pause in the mission plan so that additional reconnaissance and surveillance tasks can be performed. If desired, a checkpoint can also be designated as an AiTR location. Whenever an unmanned system that supports AiTR reaches one of these checkpoints it automatically performs the scan and sends the results back to the OCU. A vehicle will remain at a checkpoint until given a resume command.

To simulate secondary and tertiary tasks an unmanned system operator may perform, the OCU also has the ability to play audio cues for participants to respond to. These audio queues are pre-recorded messages that can be triggered when an unmanned system enters a region of the map or a timing event occurs. The triggering criteria and audio files to play can be configured using an XML settings file. An additional visual monitoring task can be run in conjunction with the OCU for experimentation purposes (Figure 5). During scenario execution, the visual monitoring program displays a series of gauges that are constantly in motion. Based on timing in a settings file, an event is generated which causes one or more of the gauges to enter an upper or lower limit. By pressing a reset button the gauges will return to normal levels. This task can also be used concurrently with the audio queues.

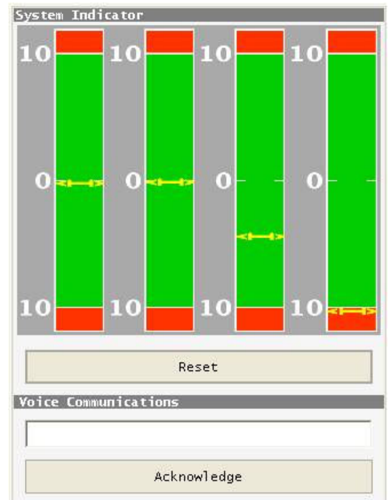

Figure 5 - Visual monitoring task

In addition to the capabilities for RSTA using the OCU, data logging capabilities also exist. The OCU data logger records all user interactions such as text fields entered, buttons pressed, scenario events (e.g. unmanned system position changes), and also performs a screen capture. This information allows researchers to keep track of what tasks a user was most heavily involved in and know what the environment looked like from the user's perspective at any point in time.

The OCU data logger is also capable of collecting data from neurophysiological sensors. This information is time-stamped so that it can be synchronized with application events. For example, if an eye tracker is used it is possible to identify what area of the screen a user was focused on when an audio queue or other event is triggered. An application interface for sending neurophysiological data to the OCU for logging allows for the addition of new sensors at a later date without needing to modify the OCU source code. Currently, the

OCU incorporates eye tracking and heart rate monitoring data for measuring a user's workload.

4. MIX SCENARIOS

The functionality provided by the MIX Testbed makes experimentation in HRI and mixed-initiative teams possible. Depending on the type of research or training desired, the test environment can be reconfigured in multiple ways due to its' distributed nature.

4.1 Mixed-Initiative Team Training

Using all components of the MIX Testbed it is possible to perform scenarios using mixed-initiative teams. With the use of DVTE, UVSIM, and the OCU a scenario can be assembled where an unmanned vehicle operator can provide reconnaissance information to a FiST team during a call for fire exercise. A simulated unmanned air system (UAS) or UGS can be generated by UVSIM in order to provide video information from the virtual battlefield. With this configuration, team training can be conducted to teach the correct procedures for interactions between the operator of an unmanned asset and other team members.

4.2 Human Robot Interactions

Current research at the ACTIVE Laboratory using the MIX Testbed involves the affects of automation on situational awareness and user workload. A standalone configuration of the OCU and UVSIM applications was used where participants were required to perform a reconnaissance, surveillance and target identification task using a simulated UGS and the OCU. Participants would monitor the environment using the video stream from the UGS, detecting unfriendly targets. In all conditions participants performed four identical missions, however the levels of automation (e.g. waypoint navigation without AiTR, teleoperation with AiTR) were varied in each mission. Additional tasks such as audio cues and visual monitoring of gauges were used to vary user workload. Using the data logging capabilities of the OCU, performance metrics, heart rate, and eye gaze were recorded to identify user workload, performance, and situational awareness under the different conditions.

4.3 Unmanned Systems Operations

With the incorporation of JAUS as a primary command and control interface, the MIX Testbed provides a means for training users how to operate unmanned systems. With JAUS, the OCU is also capable of manipulating real unmanned systems, making it an ideal environment for learning the proper mission procedures within a simulation before moving to the real thing. Moreover, JAUS is independent of hardware and technology, letting users learn a single interface for controlling air, ground, surface, or undersea unmanned systems reducing training time and costs. Users would still be required to learn the differences between platforms; however this would be required regardless of the interface.

CONCLUSION

In this paper, the design and implementation of a simulation environment for research and training with unmanned systems is described. The system design includes the ability to incorporate existing distributed simulations that are augmented by the addition of an unmanned vehicle simulation and operator control unit. The MIX Testbed is an implementation of this design which incorporates DVTE for FiST and CAS training and is enhanced by the addition of unmanned vehicle simulator and operator control unit.

The UVSIM application is capable of generating both unmanned ground and air systems that support JAUS as a primary command and control interface. Different levels of automation are supported by the simulated unmanned ground vehicle which include waypoint navigation and aided target recognition. An OCU is used to interact with simulated unmanned systems generated by UVSIM. In addition to controlling unmanned systems, the OCU incorporates data logging for user generated events and neurophysiological sensors. Several scenarios involving the MIX Testbed are presented which demonstrate how different configurations can be used for training and experimentation in HRI and mixed-initiative teams.

It is our hypothesis that the incorporation of the neurophysiological sensors and performance metrics into the testbed can lead to closed-loop, adaptive automation in the context of HRI. As a user interacts with the MIX Testbed, the system would respond to improve user performance or mitigate poor performance. In addition, the system responses can be customized to an individual, thereby "learning" strengths and weaknesses. Future efforts using the MIX Testbed will incorporate algorithms for real time analysis of the user's state which will facilitate a closed-loop adaptive system.

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